AFQTP 3E1X1-16
19 JUL 00

AIR FORCE

QUALIFICATION TRAINING PACKAGE (AFQTP)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

for

HVAC/REFRIGERATION

(3E1X1)

MODULE 16

ELECTRICAL

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MODULE 16

ELECTRICAL

Career Field Education and Training Plan (CFETP) references from 1 Apr 97 version.

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AIR FORCE QUALIFICATION TRAINING PACKAGES
for
HVAC/REFRIGERATION
(3E1X1)

INTRODUCTION

Before starting this AFQTP, refer to and read the "Trainee/Trainer Guide" located on the AFCESA Web site **http://www.afcesa.af.mil/**

AFQTPs are mandatory and must be completed to fulfill task knowledge requirements on core and diamond tasks for upgrade training. ***It is important for the trainer and trainee to understand*** that an AFQTP ***does not*** replace hands-on training, nor will completion of an AFQTP meet the requirement for core task certification. AFQTPs will be used in conjunction with applicable technical references and hands-on training.

AFQTPs and Certification and Testing (CerTest) must be used as minimum upgrade requirements for Diamond tasks.

MANDATORY minimum upgrade requirements:

Core task:

AFQTP completion
Hands-on certification

Diamond task:

AFQTP completion
CerTest completion (80% minimum to pass)

Note: *Trainees will receive hands-on certification training for Diamond Tasks when equipment becomes available either at home station or at a TDY location.*

Put this package to use. Subject matter experts, under the direction and guidance of HQ AFCESA/CEOT, revised this AFQTP. If you have any recommendations for improving this document, please contact the HVAC/R Career Field Manager at the address below.

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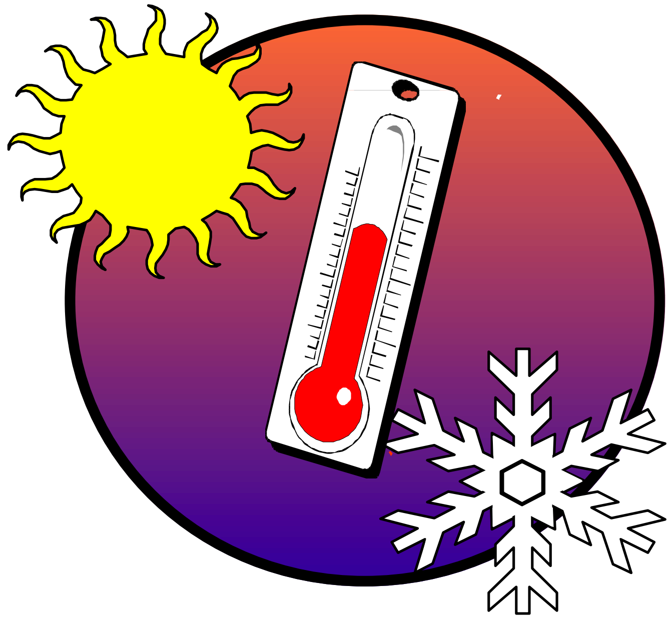

ELECTRICAL

MODULE 16 AFQTP UNIT 5

INTERPRET ELECTRICAL DRAWINGS AND SYMBOLS (16.5.)

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INTERPRET ELECTRICAL DRAWINGS AND SYMBOLS

Task Training Guide

STS Reference Number/Title:	16.5. Interpret Electrical Drawings and Symbols
Training References:	• TR: AFI32-1064; T.O.s 31-1-141 Series; • National Electrical Code; ANSI Y32.2
Prerequisites:	• Possess as a minimum a 3E131 AFSC.
Learning Objective:	• The trainee will know the steps required to safely interpret electrical drawings and symbols
Samples of Behavior:	• Trainee will be able to interpret electrical drawings and symbols

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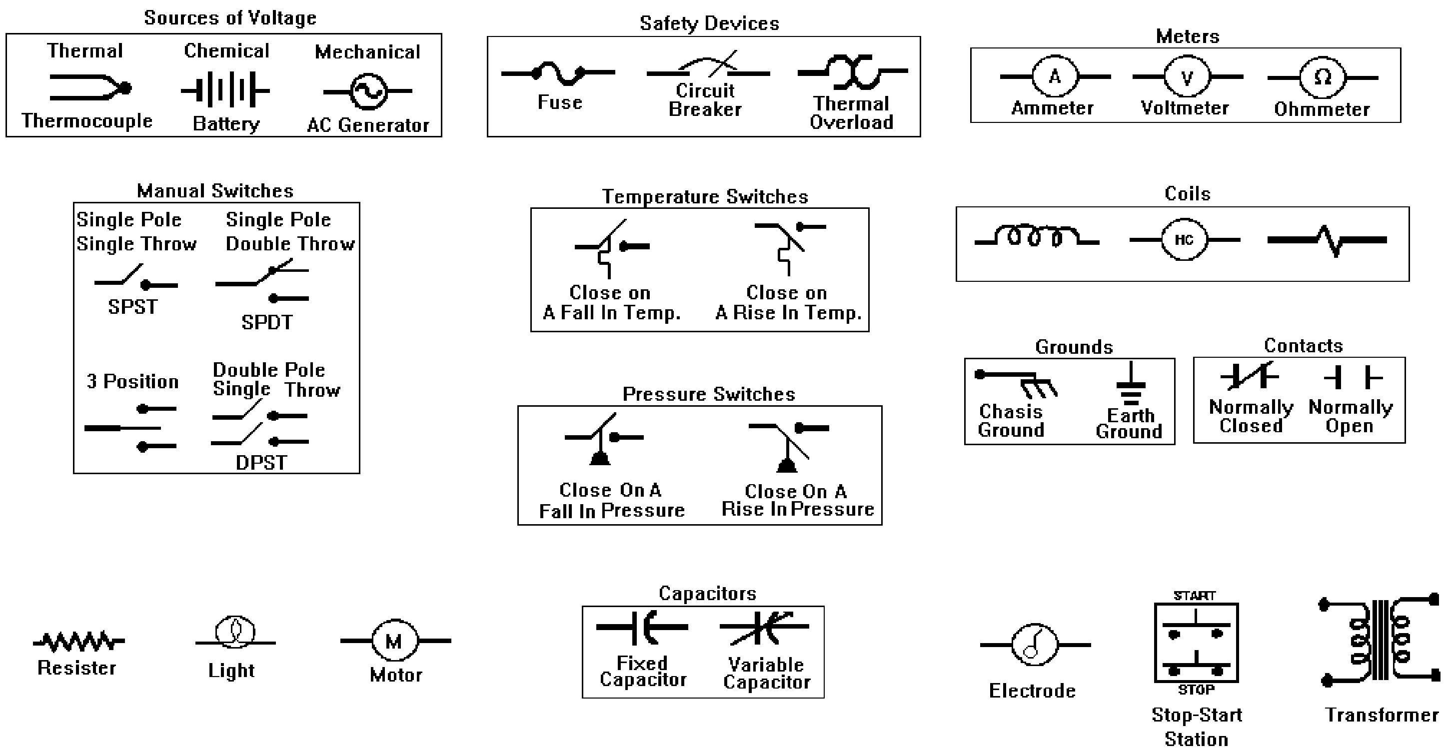
INTERPRET ELECTRICAL DRAWINGS AND SYMBOLS

Background: In your job you must be able to read and interpret electrical drawings to solve and correct problems that develop in electrical circuitry. In this section we discuss basic electrical symbols used on electrical drawings, types of electrical drawings, and how to read electrical drawings.

Electrical Symbols. Electrical symbols are used in all electrical drawings. Electrical symbols are a simple way of representing the different components in a system. Knowing electrical symbols will aid you in reading and interpreting electrical drawings for both troubleshooting and installation jobs. Electrical drawings are a form of pictorial shorthand that shows how electrical components are connected in a circuit. Most drawings come with a legend that describe the symbols used; however there are some symbols that are common to most electrical drawings, and they are often not listed in the legend. It will be worth your while to spend some time becoming familiar with electrical symbols. This will not only increase your efficiency for job accomplishment, it will allow you to concentrate on interpreting the circuit rather than just reading the drawing. Listed below in Figure 1 are some of the more common symbols that you will be required to know.

Figure 1, Electrical Symbols



Electrical Drawings. Electrical drawings (diagrams) are the "road maps" for electrical circuits. They are graphic representations of circuit operation, and each component is represented by its symbol. They tell us where the source of power is connected to the circuit, what components are in the circuit, which switches operate which loads, and what the sequence of operation is for a particular system.

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Over the years we have had many designers state their individual opinions of what symbols, or what types of diagrams should be used to explain the circuit. Since they all differed, and could not agree, the term "wiring diagram" is used as a common name for all electrical drawings. Electrical drawings are key to understanding how electrical components work together in a system. Being able to find and determine the operation of components, and entire systems, will eliminate much guesswork and frustration.

There are basically four types of electrical drawings. These drawings are similar to each other and their names are sometimes used interchangeably, but they do have differences. The four types of electrical diagrams are:

1. **The block diagram**
2. **The wiring diagram**
3. **The connection diagram**
4. **The schematic diagram**

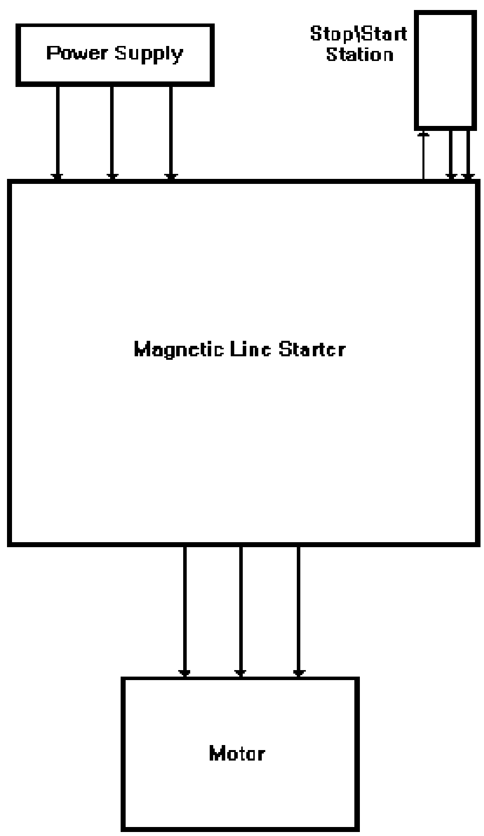

Figure 2, Block Diagram

Block Diagram. A block diagram is a simple drawing showing the relationship of major parts of a system. Figure 2 shows a block diagram of a motor control system. You can easily see why it is called a block diagram. The parts or components in any block diagram will be shown just as they appear in this drawing, as *blocks*. They are then connected by a line or lines that show the relationship of the parts. Block diagrams are often used to explain power-distribution systems. The internal connections of the components are not shown in these drawings. The blocks are simply labeled to show what component each block represents. These drawings would be of little help for troubleshooting.

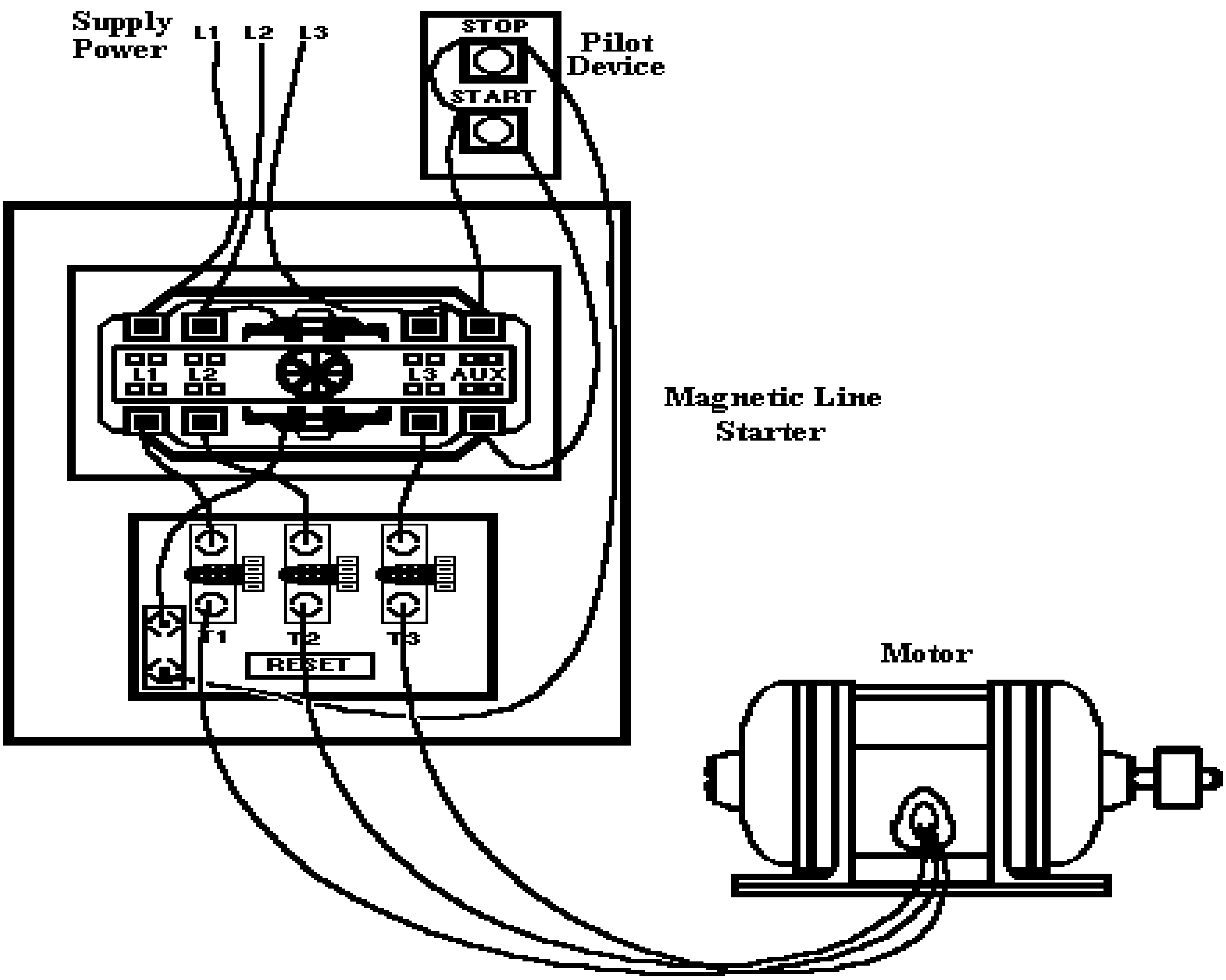

Figure 3, Wiring Diagram

Wiring Diagram. The wiring diagram, which is like a picture drawing, shows the *wiring between components* and the relative position of the components. Figure 3 shows a wiring diagram of the same motor control system shown by the block diagram. You can see that instead of blocks used to show components, a picture of the component is used. You can also see that the lines used to show the wiring is marked numerically or alphanumerically. Lines' L1, L2, and L3 are incoming power leads, and the diagram shows which terminals they are connected to in the starter. Wiring diagrams are often used along with a list of repair parts and can be used to do some troubleshooting.

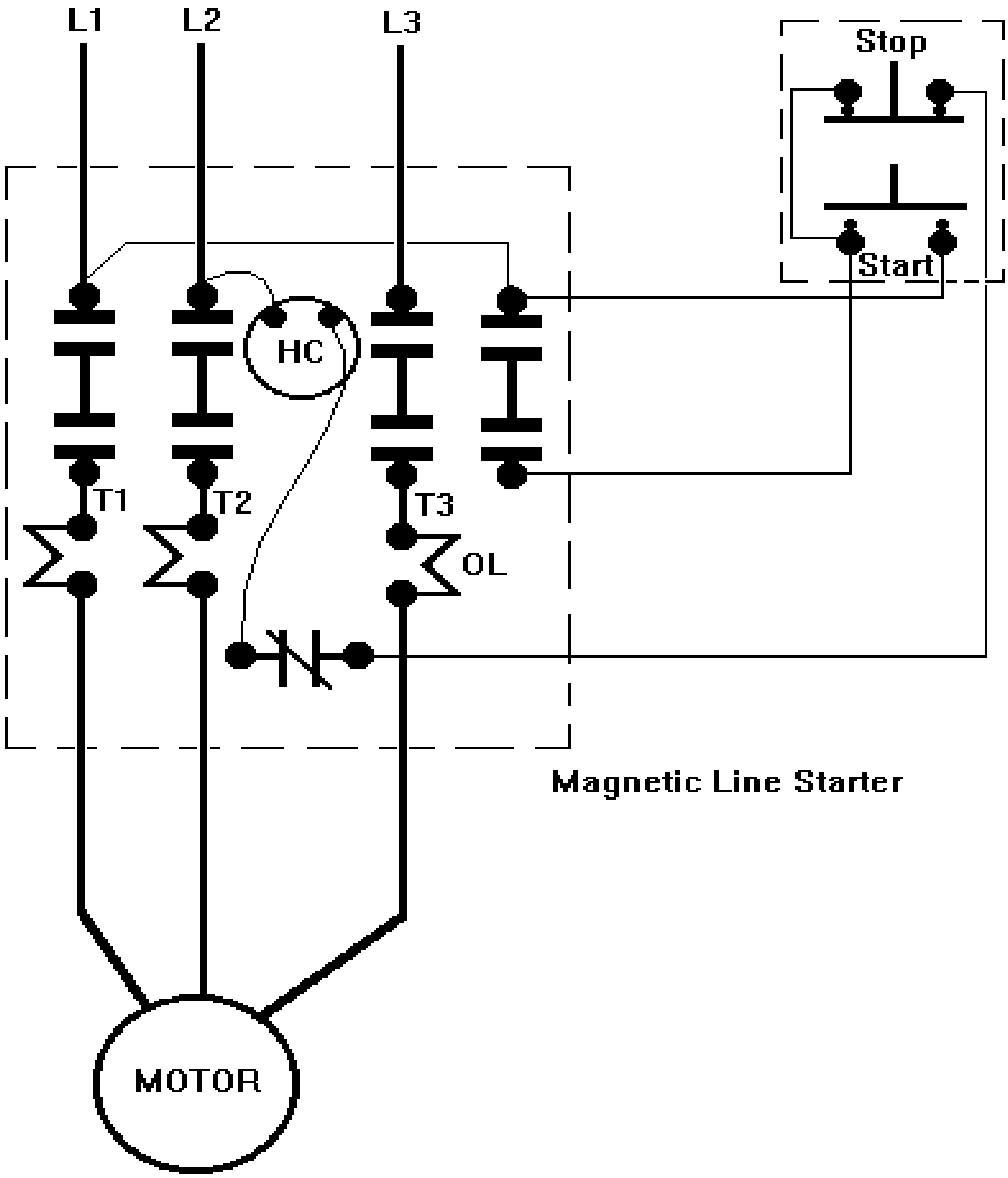

Figure 4, Connection Diagram

Connection Diagram. The connection diagram shown in Figure 4 is the same motor control system shown by the block diagram and wiring diagram. It makes use of diagram symbols instead of pictures to show components. It also shows all the <u>internal</u> and <u>external</u> circuit connections, which can be read, and traced, more easily than on the wiring diagram. In the connection diagram, the components are still shown in their relative positions. This diagram can

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be used to help you connect all the wiring and trace any part of the circuit, which makes it a very valuable troubleshooting tool. It is often found inside the cover of a piece of equipment.

Schematic Diagram. The schematic diagram is a drawing that shows the *electrical sequence of operation* of a piece of electrical equipment or component. The relative position of parts is not shown in this type of diagram. The schematic diagram, shown in Figure 5, is a plan of the same motor control system seen in the other three diagrams. It is laid out so that the components are in line to make it easy to trace the operation of the system.

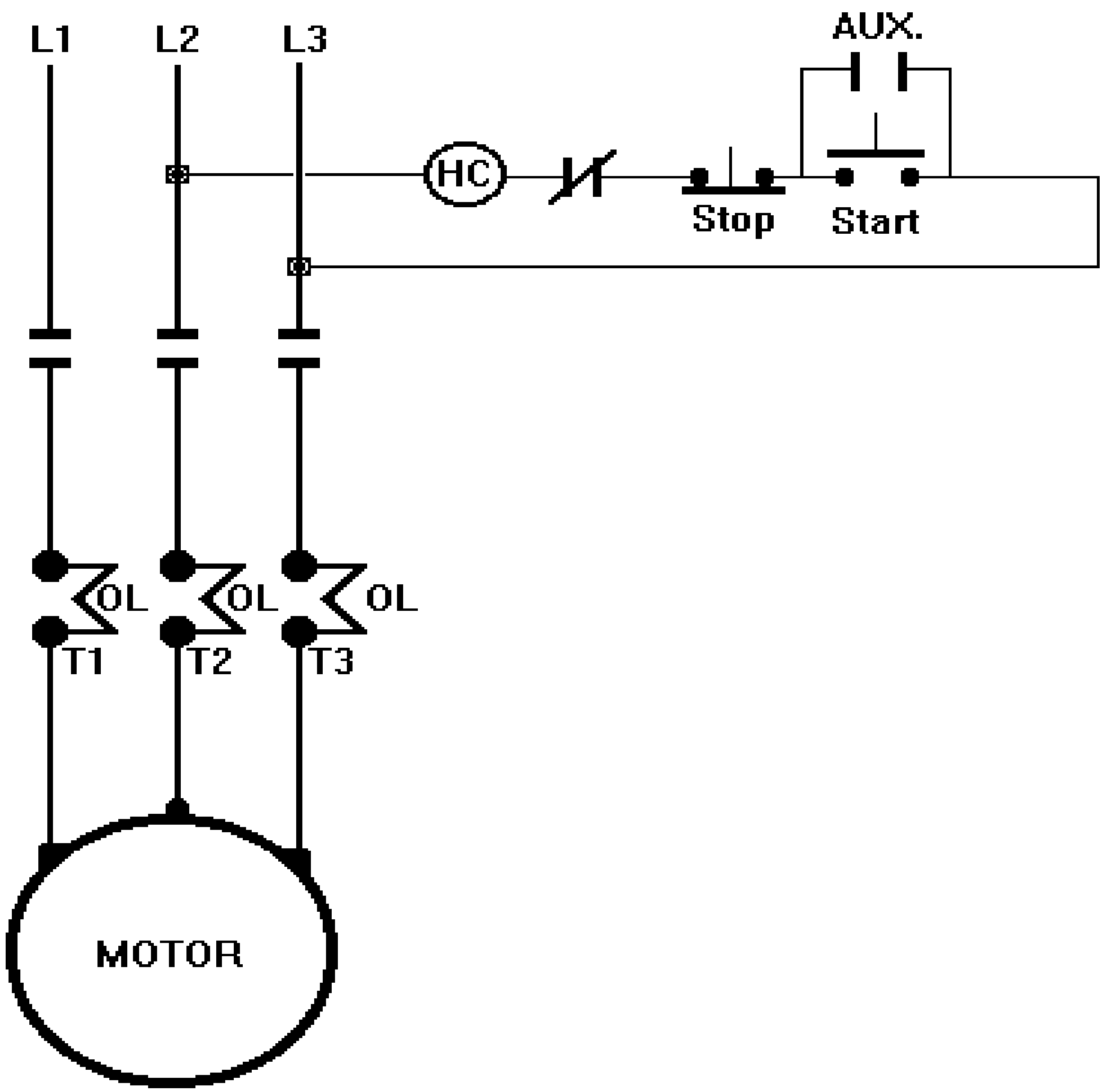

Figure 5, Schematic Drawing

Now let's look at an actual wiring diagram (Figure 6) and identify the components. Try to identify as many symbols as possible without using your symbols diagram. If you are having a hard time, review Figure 1 on page 1.

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The type of electrical drawing that you will use largely depends on the job that you are doing. Job planners normally use block diagrams to help organize or illustrate the job to be done, and the parts needed to do it. HVAC\R installers usually use wiring diagrams to aid in connecting all the components in the system. And for troubleshooting, which is what we do most commonly, the connection and schematic diagrams are the most useful.

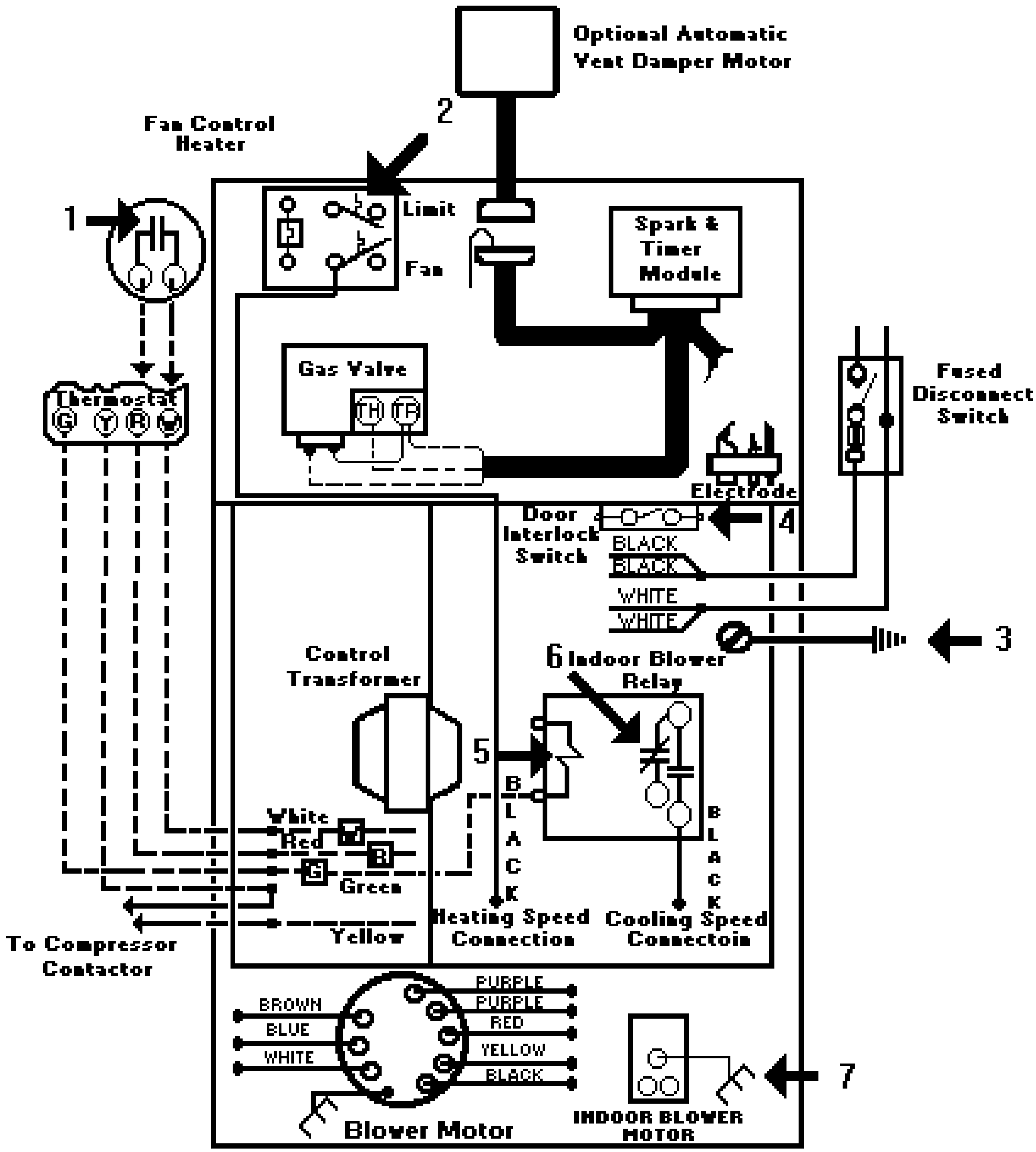


Figure 6, Gas Furnace

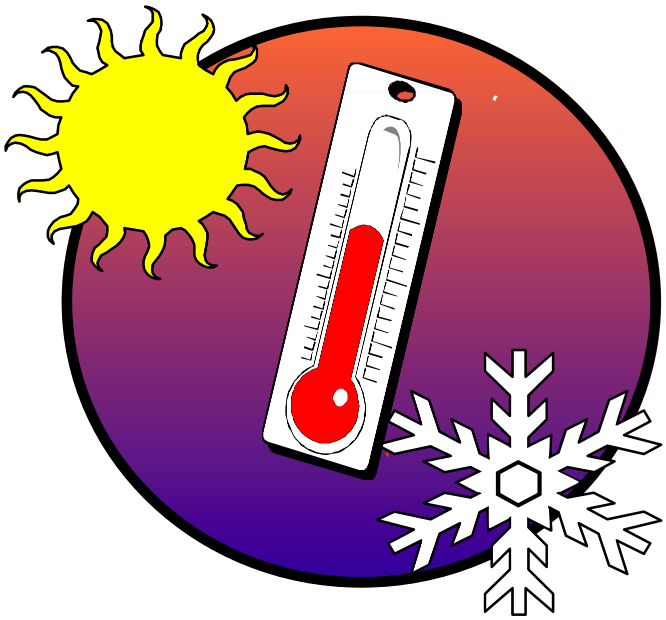
Review Questions
for
Interpret Electrical Drawings And Symbols

Question	Answer
1. A _______ diagram is a simple drawing showing the relationship of the major parts of a system.	a. Block b. Wiring c. Connection d. Schematic
2. Which diagram shows the electrical plan of operation of a piece of equipment?	a. Block Diagram b. Wiring Diagram c. Connection Diagram d. Schematic Diagram
3. Which diagram uses symbols instead of pictures and shows all the internal and external connections?	a. Block Diagram b. Wiring Diagram c. Connection Diagram d. Schematic Diagram
4. The wiring diagram, which is like a picture drawing, shows the mechanical components and the relative position of the components.	a. True b. False

INTERPRET ELECTRICAL DRAWINGS AND SYMBOLS

Performance Checklist		
Step	**Yes**	**No**
Operational Test		
1. Demonstrate Knowledge of each of the Four Types of Electrical Drawings		
a. Block Diagram		
b. Wiring Diagram		
c. Connection Diagram		
d. Schematic Diagram		
2. Demonstrate Knowledge of Electrical Symbols on a Drawing		
a. Find Safety Devices		
b. Find Coils		
c. Find the Source of Voltage Symbol		

FEEDBACK: Trainer should provide both positive and/or negative feedback to the trainee immediately after the task is performed. This will ensure the issue is still fresh in the mind of both the trainee and trainer.



MOTORS

MODULE 16 **AFQTP UNIT 9**

REMOVE OR REPLACE MOTORS (16.9.2.)

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REMOVE OR REPLACE MOTORS

Task Training Guide

STS Reference Number/Title:	16.9.2. Remove or Replace Motors
Training References:	• TR: AFI32-1064; T.O.s 31-1-141 Series; • National Electrical Code; ANSI Y32.2
Prerequisites:	• Possess as a minimum a 3E131 AFSC
Equipment/Tools Required:	• Personnel Protective Equipment • Standard HVAC/R Tool Bag
Learning Objective:	• The trainee will know the steps required to safely remove or replace motors
Samples of Behavior:	• Trainee will be able to safely remove or replace motors
Notes:	
• Any safety violation is an automatic failure	

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REMOVE OR REPLACE MOTORS

Background: It is estimated that 90% of industry use electric motors. Without motors, the wheels of industry would come to a halt, and thousands of labor saving devices would become useless. Various types of electric motors operate fans, valves, pumps and dampers. You must understand the principle of operation of electric motors in order to troubleshoot and balance motor-driven systems.

Principle Of Operation: Electric motors are rotating machines used to convert electrical energy into mechanical energy. There are primarily two types of motors used in this career field:

1. Synchronous Motors
2. Induction Motors

Synchronous Motor. The synchronous motor is used where precise movement is necessary. This motor is ideal for use in timing or cycling devices.

Induction Motor. Of all the AC motors in existence, the induction motor is the most widely used. The two types of induction motors you will need to know are:

1. Single-phase motors (1ϕ)
2. Three-phase motors (3ϕ)

Motor Construction. Practically all motors are designed to meet the requirements of a specific function. It is imperative that you get the correct motor for the job to be done. The amount of work to be done by the motor, the speed of the motor, the conditions under which it must operate, and the voltage available to the user of the motor, are all factors that determine what kind of motor will be right for the job. Although the designs of motors differ from application to application, the basic components remain the same. The three basic components of all motors are:

1. Stator
2. Rotor
3. End-Bells

Stator. The stator, or frame, serves to house the motor windings, and provide an attachment point for the supply voltage leads. The stator is made of cast iron or cast steel into which is pressed, a laminated silicone and steel core. The steel core is laminated to reduce eddy currents, which are stray currents that make the motor less efficient. This steel core is constructed with semi-closed slots that hold the field windings. The field windings are made of a number of varnish-insulated coils. The coils are insulated from the core with treated paper called fish paper. These coils are connected to each other to form the windings. The windings are either connected in a series, parallel, wye, or in a delta arrangement, which will be discussed in more detail later. The field windings and the steel core make up the stator or stationary part of the motor.

Rotor. The rotor is the rotating part of the motor. A rotor is also called an armature. The rotor provides a point to convert electrical energy to mechanical energy, and it is used to attach the motor to the load. Rotors may be either the wound, or the Squirrel-Cage type, depending on the manufacturing and the motor requirements. Squirrel-cage rotors are cheaper to build and require less maintenance than wound rotors.

- **Squirrel cage rotor.** The squirrel-cage rotor consists of a laminated silicon steel core, rotor bars, and end rings, mounted on a shaft. The rotor bars are cast into place on an angle called a skew. The skew effect increases the torque of the motor. The end rings short circuit, or connect, the rotor bars and end rings together. When one rotor bar is energized, all of them are energized. The rotor bars and end rings together make up a squirrel-cage winding. Fan blades are added on the end of the rotor to assist in providing adequate ventilation for cooling.

- **Wound rotor.** The wound rotor has a laminated silicon steel core to minimize eddy currents. This core is mounted on a shaft. The rotor winding is wound around the core in much the same manner as the coils in the stator. Each coil is made up of a number of turns of insulated copper wire. The windings are connected in the same type of configurations as the stator (series, parallel, wye, or delta). Wound rotor types of motors are used when variable speed control is desired, and a low starting current is required.

End Bells. The end bells are located at both ends of the stator. They primarily serve two functions:

1. They house bearings (which support and align the rotor and shaft).

2. They complete the frame of the motor.

Let's look at the single-phase induction motor first.

Single-Phase (1ϕ) Motors. When selecting a motor for a specific function, one of the first things to consider is the available power. If three-phase power were not available, you would have to use a single-phase (1ϕ) motor. One of the major differences between a 1ϕ and a 3ϕ motor is that the 1ϕ motor requires some means to start it, whereas the 3ϕ motor does not. Single-phase motors come in sizes from small fractional horsepower (hp) motors, up to 10 hp motors (A fractional horsepower motor is any motor rated less than one horsepower). Although they make them larger, you will rarely find a 1ϕ motor over 2 hp, because at that size 3ϕ motors are more durable, efficient, and cost effective in the long run. 1ϕ induction motors are categorized as split-phase motors, or shaded-pole motors. The different types of split-phase motors are listed below. We will look at each one individually throughout this section.

1. Resistance Start-Induction Run Motor
2. Capacitor Start-Induction Run Motor
3. Permanent Split Capacitor Motor
4. Capacitor Start-Capacitor Run Motor

- **Resistance Start-Induction Run Motor.** Resistance start-induction run motors are usually small fractional hp motors, and are normally just called split-phase motors. A split-phase motor is built much the same as any motor. It has a stator, squirrel-cage rotor, and two end bells. The construction however, is a little more complex than just the three basic parts.

The split-phase motor has two windings. One winding is of heavily insulated copper wire, which is generally located at the bottom of the stator, and is called the run, or the main winding. The other winding is called the start winding and is located in the stator, centered between and on top of the run winding. The run winding is made up of many turns of heavy copper wire; whereas the start winding is made up of more turns of smaller wire. Both sets of windings are connected to power until the motor reaches 75% of its maximum rpm.

A centrifugal mechanism, and a switch (Figure 1) have also been added to the motors basic parts. The rotating part of the centrifugal switch is on the rotor, and a stationary part (containing a set of contacts) is in the end bell. The purpose of the centrifugal switch is to remove the start windings from the circuit once the motor has reached approximately 75% of its maximum rpm. The rotating part of a centrifugal switch is a mechanism that relies on motion and flyweights to operate. As the motor turns, the flyweights are pulled out by centrifugal force. This releases pressure from the closed contacts of the centrifugal switch, which will cause them to open. These contacts are in series with the start windings, and will serve to isolate those windings from the motor circuit. Because the start winding is made up of smaller conductors, the start winding will burn up if it is not disconnected after a short period of time. It is vital to the life of the split phase motor to have a centrifugal switch that is functioning correctly.

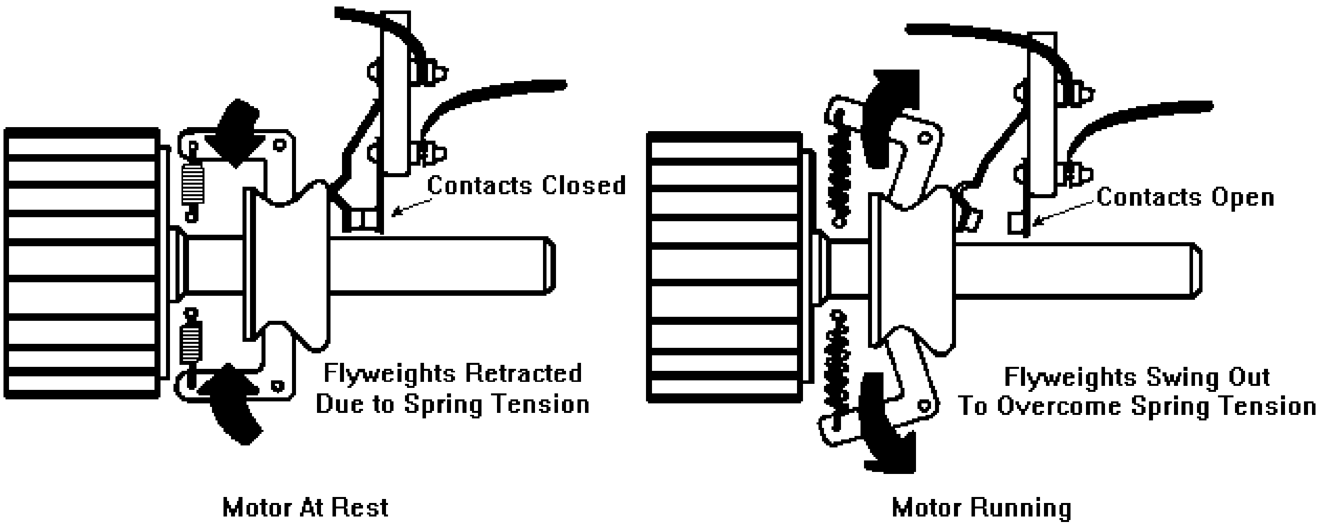

Figure 1, Centrifugal Switch

Imagine for a minute that you had a coil of wire wound in a circle. If a piece of iron was placed exactly in the center of the coil, and you applied current to the coil, what would happen to the piece of iron? The coil would develop a magnetic field that would increase and decrease in magnitude as the current flowing through it did. The magnetic field would also change direction just as the current did. With this being true, the magnetic pull or pushing on the piece of iron would be the same in all directions. This would be much the same as a tug-of-war competition that had two sides of equal strength. Under these conditions the iron in the center of the circle would not move. Now let's apply this concept to a motor.

If the stator of a motor only had one set of windings, it would induce a voltage into the rotor that would then develop a magnetic field. The magnetic field set up by the rotor will be opposite to that of the stators magnetic field, and based on what we know about magnetic attraction and repulsion, we could conclude that the rotor would be attracted to the stator. The problem with this attraction is that it will simply pull on the rotor equally in every direction and not turn the rotor. Because of this, we must establish another magnetic field that is out of phase with the rotor’s, and stator’s magnetic field, so that the attraction is at a different angle, or is at peak strength at a different time.

As stated earlier, start windings are made of smaller wire and have more turns than the run windings. This also means that the run winding will have the greater amount of current flow; thus creating the greater, or stronger, magnetic field. Remember earlier we said that inductance is the opposition to current flow, caused by the magnetic field, which is established by the current flow itself. In other words, inductance is the opposition to current flow, caused by current flowing through a coil. We also said that inductance causes current to lag behind voltage. This being the case, the current in the run winding will be further out of phase with voltage than the current in the start winding. This means that the magnetic field in the start winding will reach its peak strength before the magnetic field in the run winding. This configuration gives us a push-pull effect on the rotor and serves to begin its rotation.

The rotor of a motor is like a car setting on level ground, once you get enough force to start it rolling, it only takes a fraction of that force to keep it going. The start winding is only used for starting the rotation of the rotor. After the rotor reaches a certain rpm, the start winding is disconnected by the centrifugal switch. The rotor then continues to rotate by the shifting magnetic field in the stator, produced by the run winding only.

The split-phase motor is characterized by low starting torque (turning power) and low operating torque. It is primarily used where a 1/20th to 1/3rd hp motor is required. In our career field they can be found where we use small pumps and blowers, as those found in oil burners, and small exhaust fans.

- **Capacitor Start-Induction Run Motor.** A capacitor start-induction run motor (commonly called capacitor start motor) is an improved version of the basic split-phase type motor. A capacitor is connected in series with the centrifugal switch and the start winding. When the motor reaches 75% of full speed, the centrifugal switch opens, which removes the start windings and the capacitor from the circuit. The capacitor, along with the start windings, give the motor a greater starting torque than a basic split-phase motor.

To create a starting torque in a capacitor motor, a strong rotating magnetic field has to be established in the motor. This is done by placing the start winding out of phase with the run windings. In the split phase motor, we relied on the induction of the run winding to create a difference between the phases of the two windings. In the capacitor-start motor, we will use a capacitor in series with the start winding, to create an even greater phase difference between the phases of the two windings. The effect that capacitance has on current is just the opposite of the effect that inductance has on current. Once again, remember that capacitance causes current to lead voltage. In other words a capacitor will cause the current in the start winding to reach its maximum value before the current in the run winding becomes maximum. By using inductance to cause current to lag behind voltage in the run winding, and by using a capacitance to cause the current to lead voltage in the start winding, we can create an even greater phase difference between the current flowing through the two windings. This configuration will give us a push-pull effect on the rotor that will serve to begin its rotation. Like the split-phase motor, once the rotor reaches a certain rpm, the start winding is disconnected by the centrifugal switch. The rotor then continues to rotate by the shifting magnetic field in the stator, produced by the run winding only.

The capacitor-start motor has a much higher starting torque, but it is still only capable of operating under low torque conditions. Capacitor-start motors are usually of the 1/6th to 1 hp size, and are used in lightweight refrigeration compressors, pumps, and fans; like those found in small refrigerators.

- **Permanent Split Capacitor Motor.** The permanent split capacitor motor consists of a stator, a squirrel-cage rotor, a capacitor, and end bells. This is another version of the basic split-phase motor. A capacitor is connected in series with the start windings and is left in the motor circuit at all times. Because the capacitor will remain in the circuit, it will be of a slightly lower value than the one used in a capacitor-start motor of the same size. The start windings in this motor are not high resistance windings, and they generally have the same number of turns, and are of the same wire size as the run windings.

Instead of using the resistance of the start winding, along with the effects of capacitance to create the phase difference needed, it simply uses the capacitor to create the phase difference. So it serves to reason that the phase difference in the permanent split capacitor motor is less than that of the capacitor-start motor, yet greater than that of the split-phase motor. Therefore, the starting torque of the permanent split capacitor motor is less than that of the capacitor-start motor. Notice however that this motor does not incorporate the use of a centrifugal switch. The start windings remain in the circuit while the motor is running at maximum speed. It is for this reason that the start windings in this motor are of the same size and weight as the run windings.

The permanent split capacitor motor has a greater running torque than any of the previously mentioned motors, because the start windings stay in the circuit throughout its operation. This ensures that a phase difference is maintained while the motor is in operation, which allows this motor to operate at a constant speed under high load conditions.

- **Capacitor Start-Capacitor Run Motor.** The capacitor start-capacitor run motor consists of a stator, a squirrel-cage rotor, a capacitor, a centrifugal switch, and end bells. This motor incorporates the advantages of both the capacitor-start motor (high starting torque), and the permanent split capacitor motor (high running torque). As with the permanent split capacitor motor, both the run windings and start windings stay in the circuit at all times. This motor has two capacitors connected in parallel with each other, and in series with the start winding. One capacitor is continuously rated (the run capacitor) and stays in the circuit; the other is intermittently rated (the start-capacitor) and is used in the start circuit.

This motor actually uses both capacitors in the circuit for starting, which produces a high starting torque. Once the motor reaches 75% of its maximum rpm, the start-capacitor is removed from the circuit by the centrifugal switch; leaving the run capacitor in the circuit to maintain the phase difference between the two windings during motor operation. Thus, this motor has the highest starting torque of the four split-phase motors, and good running characteristics such as high operating torque, and constant speed under high load conditions. The schematics for the four types of split-phase motors are illustrated in Figure 2. below.

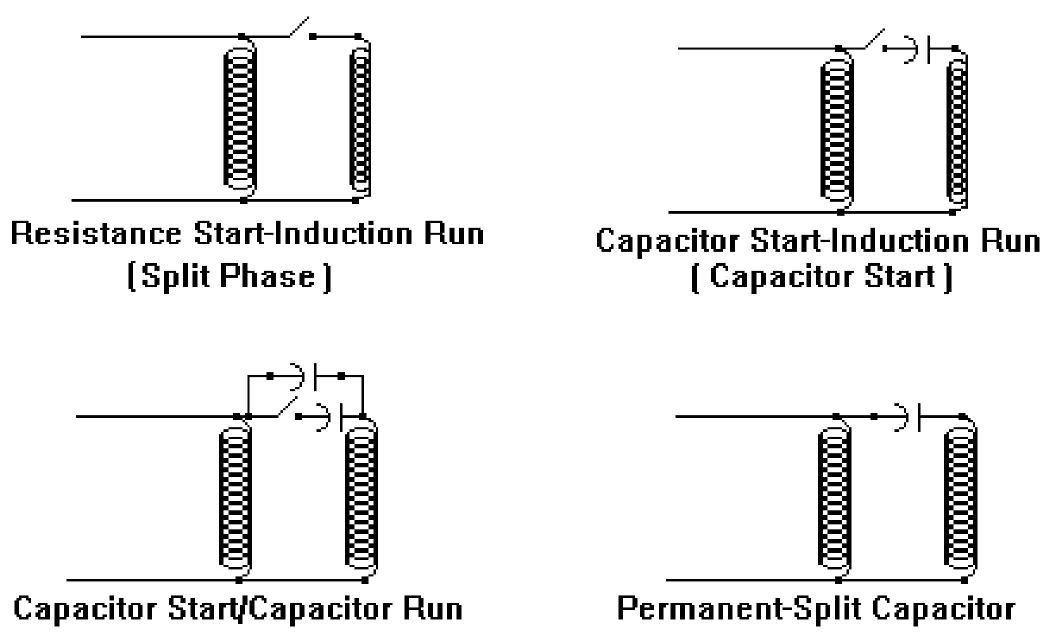

Figure 2, Schematics for Split-Phase Motors

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It should be noted that if the capacitors for the capacitor-start motor, the permanent split motor, and the capacitor-start/capacitor-run motor need to be replaced, they should be replaced with a capacitor of the same rating. In the event that a capacitor of the same rating is unavailable, a capacitor of one size larger can be used. Never use a capacitor of a lower rating, as this would cause the motor to burn up.

The direction of rotation for a split-phase motor can be reversed by changing the direction of flow through the start windings. This can be done by simply swapping the leads of the start windings, to the terminals, or leads that they are connected to. Some manufacturers make the start winding leads easily accessible to the technicians, which makes it convenient to change the rotation of the motor. However, often times split-phase motors have the start windings internally connected and are not accessible to the technician. In this case the rotation of the motor cannot be readily reversed.

Three-Phase (3ϕ) Motors. 3ϕ motors are made up of the same three basic parts of a motor as the 1ϕ motor, without having to incorporate the use of a centrifugal switch or capacitors. Unlike 1ϕ motors, the 3ϕ motors do not require a starting device; therefore their construction tends to be less complex than that of the split-phase motors. Instead of a start winding and a run winding, 3ϕ motors have three sets of windings (one for each phase) wound in the stator of the motor.

3ϕ motors have both internal and external connections. All 3ϕ motors are wound with coils. These coils are connected to each other internally, to make three separate windings or phases in the stator. The windings of all 3ϕ motors have either a Wye or Delta connection. The internal connections determine if the windings are connected for a Delta or Wye. The external connections are made with the leads that are brought out of the motor, and they are available for the technician to wire the motor for different voltages or speeds.

Some 3ϕ motors are single-voltage, and others are dual-voltage. This means that the single-voltage motor will operate at one particular voltage (220 volts). The dual-voltage motor will operate at two different voltages (220 or 440 volts). A single-voltage 3ϕ motor will require only three leads to be brought out of the motor. A dual-voltage 3ϕ motor will normally have nine leads coming out of the motor, and we will connect them using different combinations, which will be dictated by the source of voltage we have available.

All induction motors depend on the existence of a rotating magnetic field for their operation. When we discussed the 1ϕ motors, we saw that we had to create a second magnetic field that was out of phase with the initial magnetic field, in order to get the motor to turn. This is not a problem for 3ϕ motors, because by their construction, and the characteristics of 3ϕ current, we already have three magnetic fields that are out of phase with each other by 120 electrical degrees. Remember earlier we said that at any given time, all three of the phases of 3ϕ current are never equal in strength, or direction. This means that the magnetic fields in a 3ϕ motor stator are never equal. As a matter of fact, when one phase is pulling, another is pushing, and since the currents in each phase are 120° out of phase with each other, a high starting and operating torque is established, and maintained throughout the motor's operation. 3ϕ motors are categorized according to how the windings are connected in the stator. The two types of 3ϕ motors that we will discuss are:

1. The Wye-Connected 3ϕ Motor

2. The Delta Connected 3ϕ Motor

The rotating magnetic field is set up by the rise and fall of current in the stator windings. When the current reaches its maximum value in one winding, this winding produces a strong magnetic field. As the current in the first winding decreases, the current in the next winding increases. This will cause the strong magnetic field to move to that winding. As the current decreases in the second winding, it increases in the third winding. This will cause the magnetic field to move again. The windings are wound in the stator so that this rotation of the magnetic field is uniform and continuous.

These magnetic fields cut across the rotor, inducing voltage in the rotor. This voltage will cause a current to flow in the rotor that produces a magnetic field in the rotor, which is opposite in polarity to the magnetic field that produced it. Based on the magnetic principle that unlike poles attract each other, the rotor follows the rotating magnetic fields in the stator, causing the rotor to rotate. This means that the rotor will not rotate fast enough to catch up to the rotating magnetic field. If the rotor were to catch up to the rotating magnetic field, the rotors magnetic field would be positioned in such a way that the attraction to the stator would be linear instead of rotational. In other words the stator would pull directly outward instead of at an angle to cause the rotor to rotate. The rotor revolves just slow enough to allow the rotating magnetic field in the stator, to induce a magnetic field in the rotor that is positioned slightly behind the rotating magnetic field in the stator. This difference in speed is called the slip of the motor. The greater the load on the motor, the greater the slip will be; that is the slower the rotor will turn, but even at full load, the slip is not great enough to cause the magnetic field in the stator to lap, or pass, the magnetic field in the rotor. Motor slip is an inherent feature of induction motors. If the rotor's rotation is fast enough to make the attraction between the stator and rotor linear, the torque of the motor will decrease which will cause the rotor to slow down until the angle of attraction is such, that the motor achieves optimum torque. If the motor is overloaded, the motor slip would then increase to the point where the magnetic field of the stator passes and overtakes the magnetic field in the rotor, which will cause the motor to surge. This situation will cause the motor windings to overheat and break down, and should be avoided at all times.

- **Wye Connected Motor.** The symbol for a wye-connected motor is the symbol Y, sometimes referred to as a star. Figure 3 shows a schematic diagram of a wye-connected dual-voltage motor. Leads 10, 11, and 12 are connected together (normally done inside the motor by the manufacturer). These leads are the internal connections that form the Y. The remaining nine leads are brought out of the motor for the external connections.

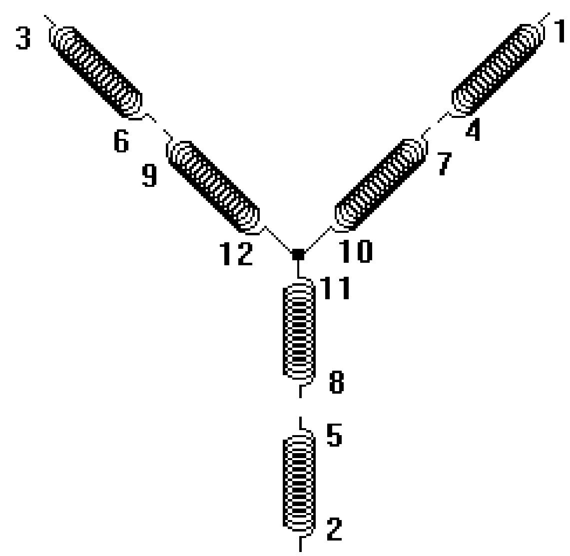

Figure 3, Schematic for a Wye Connected Motor

Notice in Figure 4 that 208/220 volts is low voltage, and 440 volts is the high voltage. This information will be given on the motor data plate, which we will discuss later. Let's look at the connections for both high and low voltage of a dual-voltage three-phase motor.

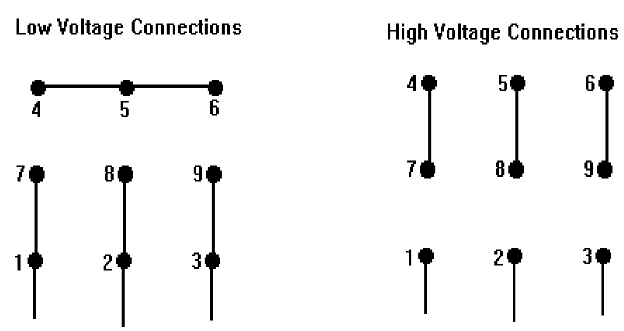

Figure 4, High and Low Voltage Connections for a Three-Phase Wye Connected Motor

Notice. This AFQTP is *NOT* intended to replace the applicable technical references nor is it intended to replace hands-on training. It is to be used in conjunction with these for training purposes only.

Figure 5 shows a 3ϕ wye-connected motor for low voltage (208/220 volts). The low voltage connections are made by splicing leads 4, 5, and 6 together and taping the connections. Leads 1 and 7 are spliced together and connected to one of the leads of the 3ϕ power. Respectfully, leads 2 and 8 and 4 and 9 are spliced and connected to the other two power leads. Windings 1-4 and 7-10 are in parallel, as well as, 2-5 and 8-11 and 3-6 and 9-12. Placing these windings in parallel causes the impedance of the windings to decrease. If you recall your study of Ohm's law, when resistance decreases, current increases, therefore, when a motor is connected for low voltage, it will draw more current than if connected for high voltage.

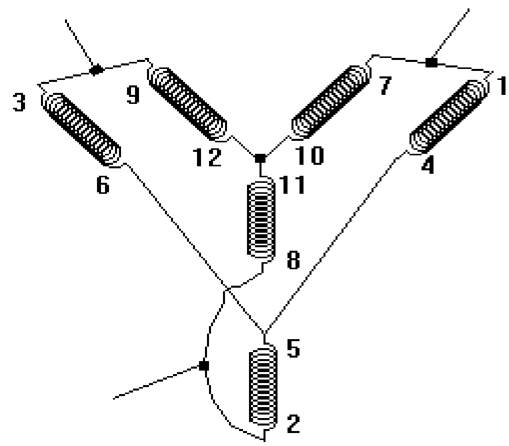

Figure 5, Wye Connected Motor for Low Voltage

Figure 6 shows a schematic diagram of a wye connected motor for high voltage. Leads 1 through 9 are brought out of the motor in the terminal box. For high voltage, leads 4 and 7 are spliced together and taped, the same as 5 and 8 and 6 and 9. The 440-volt 3ϕ power is connected to leads 1, 2, and 3. Each phase is connected separately and taped. For example, the A phase of power is connected to lead 1 of the motor. Thus, we have electrically connected the windings in series for high voltage.

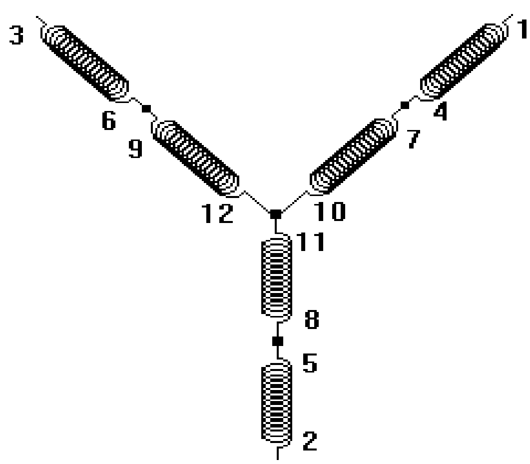

Figure 6, Wye Connected Motor for High Voltage

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- **Delta Connected Motor.** The symbol for a delta-connected motor is the Greek letter delta (Δ). Figure 7 shows a dual-voltage delta connected motor. Leads 10, 11, and 12 are connected inside the motor to leads 1, 2 and 3 respectfully. Leads 1 through 9 are brought out in the terminal box of the motor.

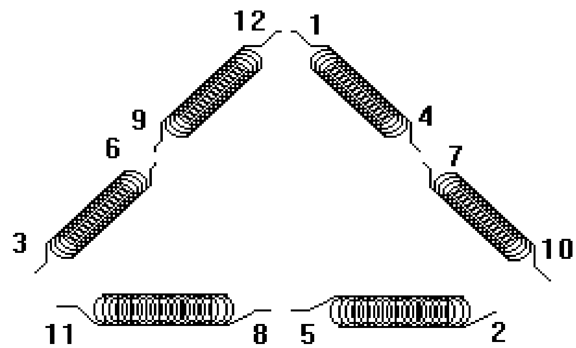


Figure 7, Schematic for a Dual Voltage Three-Phase Delta Connected Motor

Figure 8 shows a schematic diagram of a delta connected motor for high voltage (440 volts). This is accomplished by connecting leads 4-7 together and taping the connection. Leads 5-8 and 6-9 are also spliced and taped. Leads 1, 2, and 3 are connected to the power source. This configuration has the windings placed in series for high voltage.

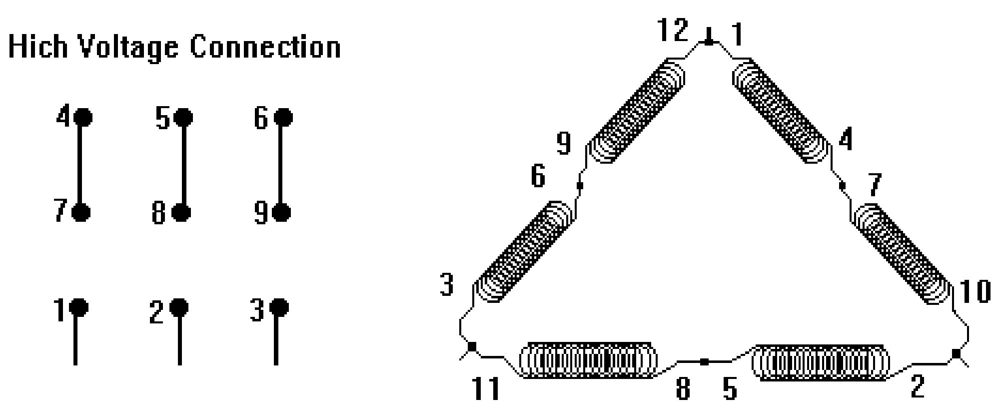


Figure 8, Delta Connected Motor for High Voltage

Figure 9 shows a schematic diagram of a delta connected motor for low voltage. Connecting leads 1-6-7, 2-4-8, and 3-5-9, in this manner, places the windings in parallel. Therefore, we will have a higher current draw when connected for low voltage. Remember, leads 10, 11, and 12 are connected inside the motor to leads 1, 2 and 3.

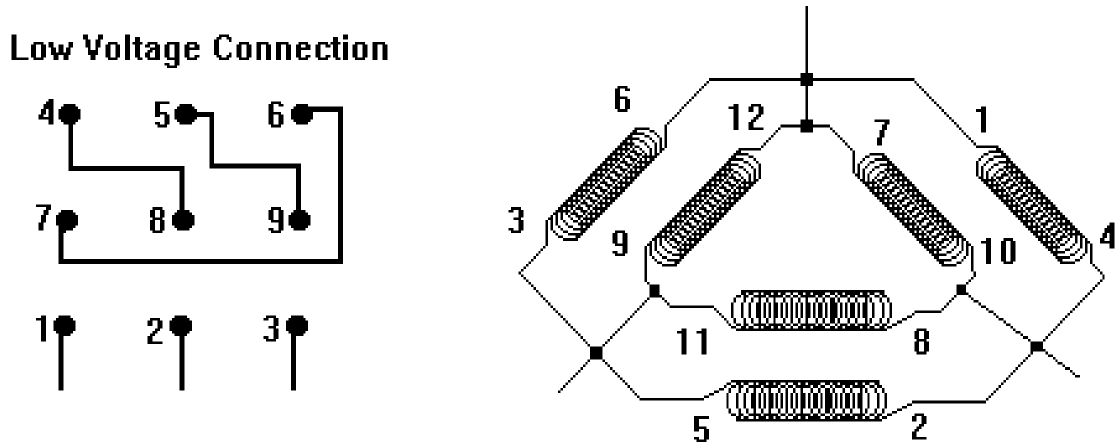


Figure 9, Delta Connected Motor for Low Voltage

As you can see by the schematic diagrams, placing the windings in series offers more impedance than the parallel connection. Therefore, a motor connected for low voltage (connected in parallel) will draw more current than if connected for high voltage. You should understand that the current flow through each coil would be the same for high or low-voltage connections.

Remember, you must have three-phase power to operate a three-phase motor. To determine the direction of rotation of a 3ϕ motor, you should start it before you connect the load. If the rotation is incorrect, you can change any two power leads to reverse the rotation of the motor; however it is recommended that you swap leads one and three.

Motor Hook-Up. This section focuses on electric motor hook-up. We'll begin with a review of electrical safety procedures. Connecting the motor to power involves selecting the proper power source, which means you will have to be able to interpret the information on the motor data plate, and be able to test the power source to see if it's correct. It will also show you how to select the right motor terminals for both single and dual-voltage motors.

Electrical Safety. Everything you do with electrical equipment, whether it is operating, testing, calibrating, overhauling, repairing, maintaining or even cleaning, provides an opportunity for accidents and/or injury. As you prepare to work on electric motors, always remember these precautions:

- Use the "buddy system." If possible, never work alone; your buddy may save your life.
- Remove electrical power from the system you're planning to work on, both at the source and at the unit you are working on.
- Remove fuses; lock-out disconnects, or open circuit breakers. Be sure to tag any source that you have secured, and use safety switches if they are there.
- If you have to troubleshoot with power on, position your buddy by the main power switch or circuit breaker panel. Make sure he or she knows first aid and CPR procedures before starting your work.
- Remove jewelry; cover metal buttons, snaps, and buckles. Metal objects can cause shorts, which may burn whatever part of your body they touch. Objects that encircle fingers, wrists and necks can catch or snag on pieces of equipment.
- Do not wear loose clothing or long hair, especially around moving equipment such as motors. Never reach over running motors.
- Use only one hand when possible; do not complete an electrical circuit with your body.
- Use tools with insulated handles.

Interpret Motor Data Plate. Before you connect an electric motor to a power source, you must know some things about the motor. The information needed will be located on the motors' data plate. Figure 10 shows a typical motor data plate. Following the figure is a list of data plate terms and their definitions.

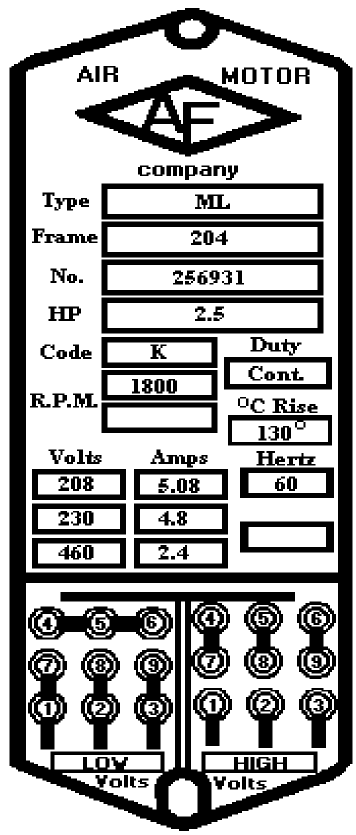


Figure 10, Typical Motor Data Plate.

Motor: A device that changes electrical energy into mechanical energy.

Horsepower Rating: Amount of work a motor is rated to do.

Phase: (Ph) - (ϕ) - Designates the type of electrical power the motor is designed to use; single-phase (1ϕ), or three-phase (3ϕ).

Capacitor: A charge stored by a capacitor is used by some single-phase motors to improve their operating characteristics. Two types are "start" and "run." A capacitor is measured in microfarads (ùF). **WARNING - Before handling a start-capacitor, it should be discharged!**

Locked-Rotor: (Amperage L.R.A.) The amount of amperage consumed by a motor when it is first turned on, or locked-up.

Full Load: The amount of amperage consumed by a motor when it is (Amperage (F.L.A.) delivering its rated horsepower.

Revolutions: The number of shaft rotations in one minute (rpm).

Insulation Class: The type of insulation used on motor windings determines the maximum allowable operating temperature; (i.e., Class A = 90°C, Class B = 110°C, Class H = 150°C, etc.)

Rotation: Refers to the direction of rotation of the motor shaft as viewed from a designated end of the motor; clockwise (CW) or counter-clockwise (CCW).

Multiple Speed Motor: A motor that can operate at more than one speed.

Continuous: The type of operation the motor is rated for.

Universal: A motor that can operate on single-phase AC or DC.

Hertz (Cycles per second): Alternating current change's direction at a certain rate, or frequency. The frequency of AC is measured in hertz. Household and commercial electricity is 60 hertz in the United States; 50 hertz in Europe.

Motor Electrical Connections:

Single Voltage (1ϕ) Motor. Single-phase AC motors are manufactured for single voltage or dual voltage applications. They can also be reversible or non-reversible. 1ϕ AC motors are made to operate on a common 1ϕ AC voltage; (i.e., 120VAC, 208VAC or 240VAC.) Motors will have a diagram of the proper terminal connections to be made on the data plate, or on the inside of the cover to the terminal connection box. The single voltage, non-reversible motor has only two leads, T1, and T2. The reversible version has four leads numbered T1, T2, T5 and T8. T5 and T8 are the leads to the start winding, and by reversing the flow of current through the start winding you can reverse the direction of rotation of the motor.

Dual Voltage (1ϕ) Motor. A dual voltage non-reversible motor has four leads, T1, T2, T3, and T4. The reversible version of this motor has six leads that are numbered T1, T2, T3, T4, T5 and T8. Lead's T5 and T8 are the leads to the start winding, and are made available to the technician, so that the rotation of the motor can be changed.

In order to operate a dual voltage motor on high voltage, the run windings must be connected in series. Lead's T1 and T2 go to one set of windings, while T3 and T4 go to another set. Connecting T2 and T3 together connects the run windings in series for 240VAC use.

Connecting T1 and T3, and T2 and T4, would put the windings in parallel, which would be the proper connection for this motor to operate at 120 volts.

The start winding is always connected in parallel with the run winding, regardless of which voltage is connected to the motor.

Single Voltage (3ϕ) Motor. Three-phase AC motors are manufactured for single voltage or dual voltage applications. All three-phase motors are reversible. 3ϕ AC motors are made to operate on a common 3ϕ AC voltage; (i.e., 208VAC, 240VAC, or 480VAC.) Three-phase motors will have a diagram of the proper terminal connections to be made on the data plate, or on the inside of the cover to the terminal connection box. The single voltage motor has only three leads, T1, T2, and T3.

Dual Voltage (3ϕ) Motor. A dual voltage 3ϕ motor has nine leads, T1, T2, T3, T4, T5, T6, T7, T8, and T9. In order to operate a dual voltage 3ϕ motor on high voltage, the windings must be connected in series. Leads T1, T4, and T7 go to one set of windings, while T2, T5, and T8 go to another set. This leaves leads T3, T6, and T9 for the third set of windings. Connecting T4 and T7 together connects the first set of windings in series, connecting T5 and T8 together connects the second set of windings in series, and by connecting T6 and T9 together connects the third set of windings in series. This configuration, that has all of the windings in series, sets the motor up for high voltage operation.

By connecting T4, T5, and T6 together, and connecting T1 to T7, T2 to T8, and T3 to T9 you have connected the windings in parallel, which is the proper configuration for low voltage operation of the motor. All 3ϕ motors are reversible by simply swapping two of the three supply leads. It is recommended that you swap L1 and L3.

NOTE:
Remember to always check the circuit that you are about to work on before actually making any connections.

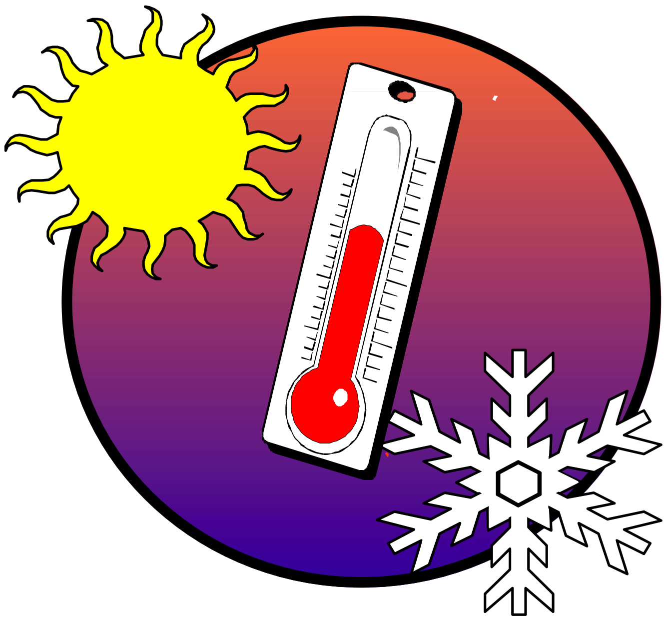
Review Questions for Remove or Replace Motors

Question	Answer
1. What is a device that changes electrical energy into mechanical energy?	a. Battery b. Capacitor c. Motor d. Switch
2. Where would you find a motor's startup amperage rating?	a. Motor Shaft b. CDCs c. Supervisor d. Motor Data Plate
3. A synchronous motor is used where precise movement is necessary. This motor is ideal for use in timing or cycling devices.	a. True b. False
4. The three basic components of all motors are: Starter, Motor, and End-Bells.	a. True b. False
5. The Permanent Split Capacitor motor consists of a ________________________ .	a. Stator, a squirrel-cage, a capacitor, and end bells. b. Starter, a squirrel-cage, a capacitor, and end bells. c. Stator, a squirrel-cage, a in-capacitor, and end bells. d. Stator, a squirrel-cage, a capacitor, and ohm- bells.
6. The Capacitor Start-Capacitor Run Motor consists of a stator, a squirrel-cage rotor, two capacitors, a centrifugal switch, and end bells.	a. True b. False
7. A Dual Voltage 3ϕ Motor has __________ .	a. Nine leads, T1, T2, T3, T4, T5, T6, T7, T8, and T9. b. Four leads, T1, T2, T3, and T4. c. Four leads, T1, T2, T5 and T8. d. Six leads, T1, T2, T3, T4, T5 and T8.

REMOVE OR REPLACE MOTORS

Performance Checklist		
Step	**Yes**	**No**
Operational Test		
1. Demonstrate Removing and Replacing a Single Voltage, Single-Phase Motor.		
a. Safety Procedures		
b. Disconnect Power and Wiring to Old Motor		
c. Disconnect Old Motor and Rewire in the New Motor		
d. Operational Test of New Motor		
2. Demonstrate Removing and Replacing a Single Voltage, Three-Phase Motor.		
a. Safety Procedures		
b. Disconnect Power and Wiring to Old Motor		
c. Disconnect Old Motor and Rewire in the New Motor		
d. Operational Test of New Motor		

FEEDBACK: Trainer should provide both positive and/or negative feedback to the trainee immediately after the task is performed. This will ensure the issue is still fresh in the mind of both the trainee and trainer.



REPAIR COMPONENTS

MODULE 16 **AFQTP UNIT 11**

TROUBLESHOOT ELECTRICAL CIRCUITS & COMPONENTS (16.11.1.)

CORRECT MALFUNCTIONS (16.11.2.)

Notice. This AFQTP is *NOT* intended to replace the applicable technical references nor is it intended to replace hands-on training. It is to be used in conjunction with these for training purposes only.

TROUBLESHOOT ELECTRICAL CIRCUITS & COMPONENTS

CORRECT MALFUNCTIONS

Task Training Guide

STS Reference Number/Title:	16.11.1. Troubleshoot Electrical Circuits & Components 16.11.2. Correct Malfunctions
Training References:	• TR: AFI32-1064; T.O.s 31-1-141 Series; National Electrical Code; ANSI Y32.2 • CD ROM 3E1X1-16.11.1. / 16.11.2. “HVAC Electrical Troubleshooting and Repair” Version 1.0
Prerequisites:	• Possess as a minimum a 3E131 AFSC.
Equipment/Tools Required:	• Personnel Protective Equipment • Standard HVAC/R Tool Bag
Learning Objective:	• The trainee will know the steps required to safely troubleshoot electrical circuits & components.
Samples of Behavior:	• Trainee will be able to safely troubleshoot electrical circuits & components.

Notes:
• This task is covered in the computer-based QTP entitled “HVAC Electrical Troubleshooting and Repair”, Version 1.0 • Any safety violation is an automatic failure.

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TROUBLESHOOT ELECTRICAL CIRCUITS & COMPONENTS

CORRECT MALFUNCTIONS

Background: In your job, you will be required to read and interpret wiring diagrams so that you can troubleshoot and repair circuit problems as they happen. Most of you already know something about electricity, as electrical appliances are a part of your everyday life. You flip a switch and a lamp comes on. You turn a radio knob and music fills the room. Some other electrical devices you have used are TVs, VCRs, Microwave ovens, etc. What do most people know about how these appliances really work? Not much! In this AFQTP we will discuss the basics for troubleshooting and correcting malfunctions on electrical circuits and components.

SAFETY:

EVERYTHING YOU DO WITH ELECTRICAL EQUIPMENT, WHETHER IT IS OPERATING, TESTING, CALIBRATING, OVERHAULING, REPAIRING, MAINTAINING OR EVEN CLEANING, PROVIDES AN OPPORTUNITY FOR ACCIDENTS AND/OR INJURY. AS YOU PREPARE TO WORK ON ELECTRICAL CIRCUITS AND COMPONENTS, REMEMBER THESE PRECAUTIONS:

- **USE THE "BUDDY SYSTEM." IF POSSIBLE, NEVER WORK ALONE; YOUR BUDDY MAY SAVE YOUR LIFE.**
- **REMOVE ELECTRICAL POWER FROM THE SYSTEM YOU'RE PLANNING TO WORK ON; BOTH AT THE SOURCE AND AT THE UNIT YOU ARE WORKING ON.**
- **REMOVE FUSES, LOCKOUT DISCONNECTS, OR OPEN CIRCUIT BREAKERS. BE SURE TO TAG ANY SOURCE THAT YOU HAVE SECURED, AND USE SAFETY SWITCHES IF THEY ARE THERE. IF YOU HAVE TO TROUBLESHOOT WITH POWER ON, POSITION YOUR BUDDY BY THE MAIN POWER SWITCH OR CIRCUIT BREAKER PANEL.**
- **MAKE SURE HE OR SHE KNOWS FIRST AID AND CPR PROCEDURES BEFORE YOU START WORK.**
- **REMOVE JEWELRY; COVER METAL BUTTONS, SNAPS, AND BUCKLES. METAL OBJECTS CAN CAUSE SHORTS THAT MAY BURN THE PART OF YOUR BODY THEY TOUCH.**
- **OBJECTS THAT ENCIRCLE FINGERS, WRISTS, AND NECKS CAN CATCH OR SNAG ON PIECES OF EQUIPMENT.**
- **DO NOT WEAR LOOSE CLOTHING OR LONG HAIR; ESPECIALLY AROUND MOVING EQUIPMENT SUCH AS MOTORS.**
- **NEVER REACH OVER RUNNING MOTORS. USE ONLY ONE HAND WHEN POSSIBLE.**
- **DO NOT COMPLETE AN ELECTRICAL CIRCUIT WITH YOUR BODY.ALWAYS USE TOOLS WITH INSULATED HANDLES.**

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To perform this task, view **AFQTP 3E1X1-16.11.1. & 16.11.2. Version 1.0 HVAC Electrical CD-ROM**.

NOTE:

In the CD-ROM there are tests after each section. Complete each section and answer the questions.

CerTest numbers 8109, 9110, 8112 and 8113 are mandatory for these tasks.

HINT: To improve your chances of achieving a passing score, after completing a lesson in the CD-ROM, take the corresponding CerTest.

TROUBLESHOOT ELECTRICAL CIRCUITS & COMPONENTS

CORRECT MALFUNCTIONS

Performance Checklist		
Step	**Yes**	**No**
Operational Test		
1. Demonstrate Troubleshooting an Electrical Circuit (simple circuit)		
a. Safety Procedures		
b. Disconnect Load Device from the Circuit		
c. Re-connect Load Device to the Circuit		
d. Operational Test of the Circuit		
2. Demonstrate Troubleshooting a Control Relay		
a. Safety Procedures		
b. Disconnect Power and Check out Contacts of the Control Relay		
c. Reconnect Control Relay to the Circuit		
d. Operational Test of the Control Relay		

FEEDBACK: Trainer should provide both positive and/or negative feedback to the trainee immediately after the task is performed. This will ensure the issue is still fresh in the mind of both the trainee and trainer.

Air Force Civil Engineer

QUALIFICATION TRAINING PACKAGE (QTP)

REVIEW ANSWER KEY

For

HVAC/REFRIGERATION

(3E1X1)

MODULE 16

ELECTRICAL

Notice. This AFQTP is *NOT* intended to replace the applicable technical references nor is it intended to replace hands-on training. It is to be used in conjunction with these for training purposes only.

INTERPRET ELECTRICAL DRAWINGS AND SYMBOLS

(3E1X1-16.5.)

Question	Answer
1. A _____ diagram is a simple drawing showing the relationship of major parts of a system.	a. Block
2. Which diagram shows the electrical plan of operation of a piece of equipment?	d. Schematic Diagram
3. Which diagram uses symbols instead of pictures and shows all the internal and external connections?	c. Connection Diagram
4. The wiring diagram, which is like a picture drawing, shows the mechanical components and the relative position of the components.	b. False

REMOVE OR REPLACE MOTORS

(3E1X1-16.9.2.)

Question	Answer
1. What is a device that changes electrical energy into mechanical energy?	c. Motor
2. Where would you find a motor's startup amperage rating?	d. Motor Data Plate
3. A synchronous motor is used where precise movement is necessary. This motor is ideal for use in timing or cycling devices.	a. True
4. The three basic components of all motors are: Starter, Motor, and End-Bells.	b. False
5. The Permanent-Split Capacitor motor consists of a ________________________.	a. stator, a squirrel-cage, a capacitor, and end bells.
6. The Capacitor Start-Capacitor Run Motor consists of a stator, a squirrel-cage rotor, two capacitors, a centrifugal switch, and end bells.	a. True
7. A Dual Voltage 3ϕ Motor has __________.	a. nine leads, T1, T2, T3, T4, T5, T6, T7, T8, and T9.

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